Advancing the Technology R&D of Tabletop Mesoscale Nondestructive Characterization

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This project will advance nondestructive characterization of mesoscale (mm-sized) objects, allowing μm resolution over the objects' entire volume. X-ray imaging will be developed that allows object characterization with materials that vary widely in composition, density, and geometry.

Project Goals

The overall goal is to research the science and engineering needed to nondestructively characterize and model mesoscale objects. The spatial resolution goal for this microscopy is roughly 1 μm^3 or better, while the contrast goal represents a signal-to-noise ratio of 1000:1.

Relevance to LLNL Mission

Specific LLNL programs that would benefit from this new capability include the development of novel sensors for NAI applications; the study of explosive samples for DoD and DOE; and high-energy-density physics and inertial confinement fusion experiments for NIF.

FY2004 Accomplishments and Results

We performed several types of modeling to better understand x-ray imaging of mesoscale objects. Characterization of the solid deuterium-tritium (D-T) fuel layer in an ICF capsule using a beryllium ablator requires phase-contrast imaging. We chose

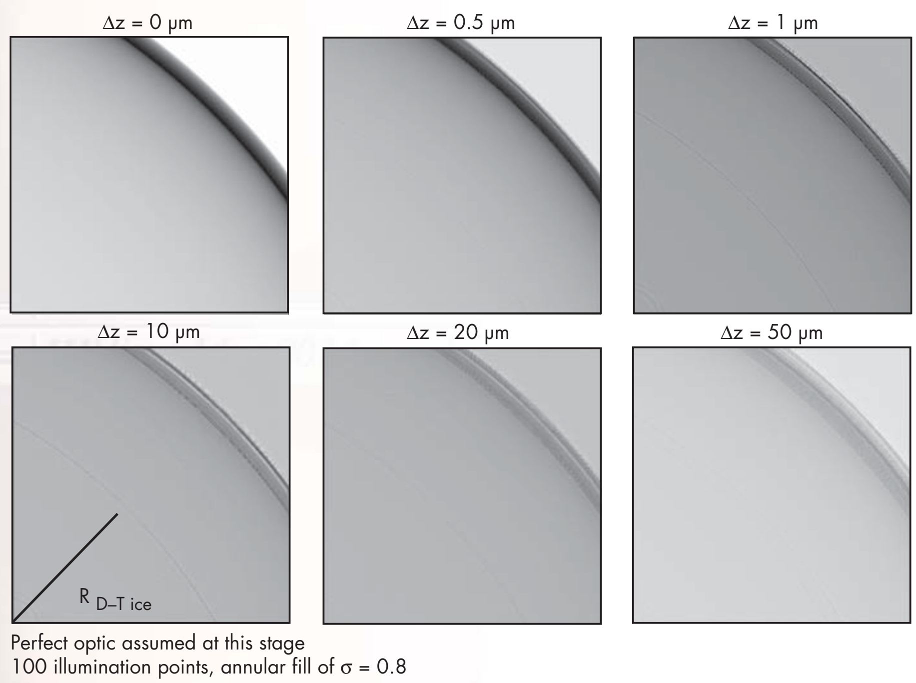

Figure 1. A perfect Wolter optic microscope simulation of a D-T ice layer inside a Be capsule. Exit-to-image-plane distances are labeled as Δz. The D-T ice gas layer is discernable for $\Delta z \geq 0.5$ μm.

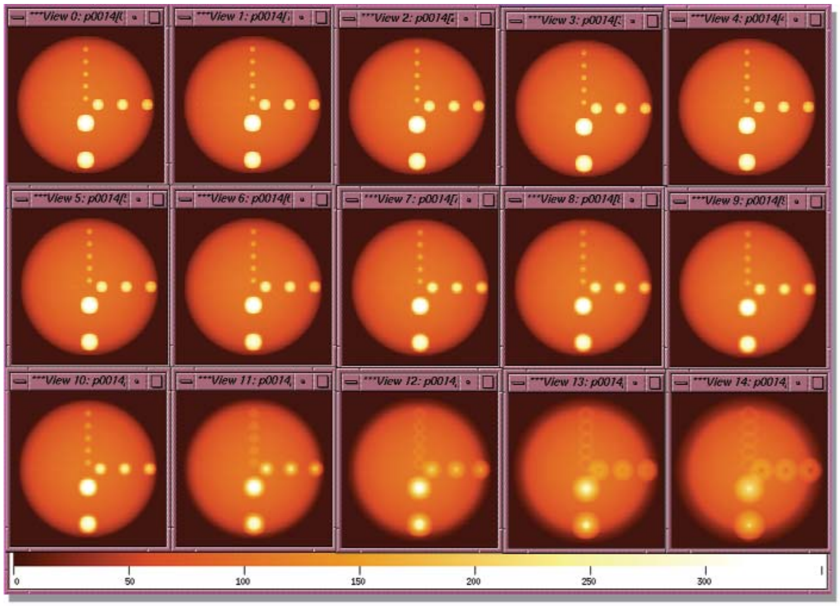

Figure 2. Simulated images of a 45-µm-diameter spherical object with a number of spherical inclusions on the center plane of the sphere. The first image has the center plane of the spherical object on the focal plane of a Wolter x-ray optic instrument. The succeeding images are the results of translations of the object toward the detector along the instrument axis. Images 2 to 10 are each 0.5 µm steps further from the focal plane (0.5 µm to 4.5 µm). The last five images are at 5, 10, 15, 20, 25 µm from the focal plane.

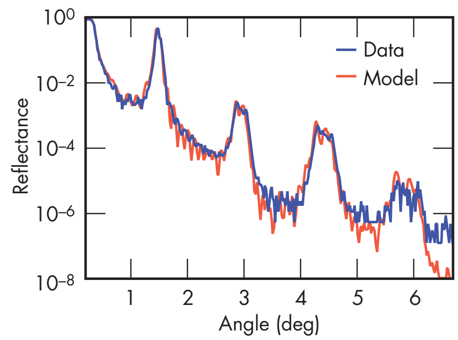

Figure 3. Measured reflectivity of the multilayer coating as a function of incident angle.

this as one example for our modeling work. We modeled projection imaging systems with a coherent parallel-beam and a point source, and a large-size source with a Wolter x-ray imaging optic (Fig. 1). These studies showed that imaging was possible with either approach.

Objects with geometric and x-ray properties comparable to an ICF capsule were used in initial experimental tests of the modeling results. These objects were successfully imaged using LLNL's KCAT system, Xradia's μXCT, and ANL's Advanced Photon Source.

We examined whether it is necessary to use the multislice method to solve the paraxial wave equation to simulate x-ray microscopy of mesoscale objects, or if ray tracing will suffice. Preliminary results reveal ray tracing was adequate for modeling the propagation of x rays through mesoscale objects of interest.

Additional modeling probed the imaging capability and limitations of a Wolter x-ray microscope system. This system was designed to characterize mesoscale objects to sub-μm spatial resolutions. A code has been developed to model the 2-D image formation in a Wolter x-ray microscope. A series of simulations using various objects were run to study the effects of the optics (Fig. 2). These simulations were analyzed using both laminographic and tomosynthesis methods.

One Wolter 8-keV x-ray optic was fabricated for the microscope, with two important results. First, the team developed a framework and methodology for the construction of high-precision optics for future efforts at LLNL. Second, we demonstrated both a laterally- and a depth-graded multilayer coating to maximize the throughput of the optic (Fig. 3).

Related References

1. Koziozemski, B. J., J. A. Koch, A. Barty, H. E. Martz, W.-K. Lee, and K. Fezzaa, "Quantitative Characterization of Inertial Confinement Fusion Capsules Using Phase Contrast Enhanced X-Ray Imaging," submitted to *J. Appl. Phys*., 2004.

2. Martz, Jr., H. E., and G. F. Albrecht, "Nondestructive Characterization Technologies for Metrology of Micro/Mesoscale Assemblies," *Proceedings of Machines and Processes for Micro-scale and Mesoscale Fabrication, Metrology, and Assembly,* ASPE Winter Topical Meeting, Gainesville, Florida, January 22-23, pp.131-141, 2003.

FY2005 Proposed Work

This initiative has evolved into two projects, one focusing on x-ray phase-effects characterization, the other on x-ray optics fabrication.